

Radio access and Transmission models for universal service

Idriss Saleh BACHAR*, Ahmed Dooguy KORA**, Roger Marcelin FAYE***, Christelle Aupetit-Berthelemot****

* *Autorité de Régulation des Communications Electroniques et Postes, BP 5808, Ndjamen, TCHAD*

** *École Supérieure Multinationale des Télécommunications, BP 10000, Dakar, SENEGAL*

*** *École Supérieure Polytechnique, BP 5085, Dakar-Fann, SENEGAL*

**** *Xlim/SRI/Resyst, UMR-CNRS 7252, University of Limoges, 16 rue Atlantis 87068 Limoges Cedex, FRANCE*

i.bachar@arcep.td, ahmed.kora@esmt.sn, roger.faye@ucad.edu.sn, christelle.aupetit-berthelemot@xlim.fr

Abstract—This paper proposes two mathematical models as a decision tool for the choice of radio access and transmission solutions adapted to a geographical region through universal access. The first mathematical model integrates the formalism related to engineering radio network access in general as well as financial constraints imposed by the access and universal service funds. The second mathematical model is the equivalent of the first applied to radio transmission systems. Services considered are voice and data services. This approach has helped to derive two general expressions set for radio access and radio transmission technologies. The coverage and capacity deployment strategy has also been combined to clarify the optimal implementation based on financial constraints. A case study on the Ouaddai and Oura regions in Chad accompanied by simulations curves for wireless technologies as Wi-Fi, WiMAX, CDMA, and Open BTS for example has shown the efficiency of such approach.

Keyword— access network model, radio access, radio access model, radio transmission, radio transmission model, universal access, universal service.

I. INTRODUCTION

Information and Communication Technologies (ICT) are crucial for the socio-economic development of peoples and contribute to the emergence of countries.

However, according to geographical membership and/or

socio-economic category, the access to ICT is achieved in a non-egalitarian and disparate manner between peoples. This technological gap is explained by the fact that neither the needs for services, nor the purchasing power are the same. This leads governments to define an investment policy fostering rural areas in order to fill the gap with dense and profitable areas. In order to raise tele-density and reduce the disparities of access, the authorities and regulatory agencies have introduced the concept of universal access and services [1-4] by dedicating a fund called Universal Service Fund (FSU).

Considering the convergence and neutrality of technologies, communications infrastructures and the associated services now have a central role in economic organization [5-9]. In fact, access to these infrastructures and services depend on the ability of countries and citizens to participate in the flow of communications. For that reason, they must put in place policies which will help to avoid the exclusion of some categories of users or geographic areas deemed to be of non-profitable nature by the operators.

In this context access and universal service could be considered as a major problem. This is to ensure that quality and price for consumer satisfaction as well as profitability from the point of view of operators might be taken into account. In order to respond to this problem, the solution should come from pairing technical/economic approaches and taking into account geographical constraints inherent to each country.

Gasmi & Recuero Virto [8] have reviewed the provision policies of telecommunications services in rural areas for developing countries. They have shown that these policies differ from those usually applied in advanced countries in their basic objectives, technological strategies deployment, the role of the market and institutional environments. Falch & Henten [10] have studied the appropriate policy measures to put in place in Europe to achieve universal access. They have shown that it is interesting to implement a combination of different technologies and strategies. Xavier [11] provides an overview of the principal issues related to universal access and the provision of universal service.

Access and universal service are influenced by accessibility parameters, cost and feasibility of services. To this end, the UAS policy should consider technological innovation as a

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Dr. Idriss Saleh BACHAR (corresponding author: +235 66204775; e-mail: i.bachar@arcep.td) is with the Regulatory Authority for Electronic Communications and Posts (ARCEP Chad), BP 5808, Ndjamen, Chad. He is currently the GENERAL DIRECTOR.

Pr Ahmed Dooguy KORA (email: ahmed.kora@esmt.sn) is with Ecole Supérieure Multinationale des Télécommunications, Dakar, Senegal. He is the Head of Research and Innovation Department.

Pr Roger Marcelin FAYE (email: roger.faye@ucad.edu.sn) is with the Electrical Engineering Department of Ecole Supérieure Polytechnique, Cheikh Anta Diop University, Dakar, Senegal.

Pr Christelle Aupetit-Berthelemot (email: christelle.aupetit-berthelemot@xlim.fr) is with XLIM Laboratory, SRI axis, Resyst Team, UMR CNRS 7252, University of Limoges, 16 rue Atlantis 87068 Limoges Cedex, France. She is professor at ENSIL.

suitable solution for UAS, covering rural areas and / or serving low-income populations.

In this paper, access radio and transmission technologies model for universal service are proposed. We have established a model of access network design common to radio technologies as well as transmission which have been adapted to universal service funds limitations. The number of base stations based on the project duration for each radio technology has been derived. This has made it possible to decide the optimal strategy deployment coupling the radio coverage for data and voice services. The efficiency of this approach is shown thanks to the case study applied to Ouaddai and Oura regions in Chad.

In the rest of this article Section 2 presents the modelling approach for determining the different elements of the access network and profitability model. Section 3 presents the radio modelling approach for determining the different elements of the transmission network and profitability model. Section 4 offers a case study that will highlight on the usefulness of the approach. Finally, Section 4 concludes this communication.

II. RADIO ACCESS MODELLING APPROACH

The optimal network modelling approach proposed consists in determining the optimal network architecture for the universal access and service in an area. The methodological approach to obtain this model is based on the access network model and that of the transmission network. The determination of the access network model of an area is carried out based on the telecommunications engineering parameters, notably those related to the demographic and financial aspects. Thus, through this area data, the population addressable to the universal access and the bandwidth and the necessary number of base stations are determined, then the investment and operation costs (CAPEX and OPEX) are assessed in addition the energy related expenses and liabilities are defined.

The population addressable to the universal service is given by the expression:

$$P_A = (P - P_S) \times T_N \quad (1)$$

where P is the population of the target area, P_S the population having access to the universal service and T_N the service penetration rate.

The bandwidth brought back to the addressable population is determined based on the data rate/subscriber need, the data rate by user supplied by an access technology and the contention rate. It is expressed by the following relationship:

$$BP_A = P_S \times D_A \times T \quad (2)$$

where D_A represents the data rate per subscriber, P_S the population having access to the universal service and T the contention rate.

It is worth noting that the data rate/subscriber simultaneously takes the voice and data into consideration and that the contention rate has to be taken so that, even in the most unfavorable case, the voice minimum output is kept for the user, which is translated by constraint expressing that the access technology has to easily bear the cost of the subscribers data rate needs. The determination of the necessary number of base stations of the access area allies a coverage approach with a capacity approach in order to avoid the network

oversizing and under-sizing problems. Thus, this number is given by the following relationship:

$$BS_{NX} = m \times BS_C + n \times BS_B \quad (3)$$

$$\text{where } BS_C = \frac{S_c}{S_{BSC}} \text{ and } BS_B = \frac{Bp_A}{CapBS_X \times T_u}$$

with S_C the surface to cover and S_{BSC} the surface covered by a base station, $CapBS_X$ the bandwidth base station capacity brought back to a technology X and T_u this station use rate, m and n are the coefficients related to the coverage and capacity needs. From equation (3), the BS_X is expressed in function of m by the following expression:

$$BS_{Nx} = (m \times BS_C + (1 - m) \times BS_B) \quad (4)$$

The total cost of the investment expenses (CAPEX) of a technology X is given by the expression:

$$C_C = BS_N \times capex(BS_X) \quad (5)$$

where $capex(BS_X)$ is the investment unit cost of a given technology X .

As for the total cost of the operation expenses (OPEX) of a technology X , taking into consideration its reducing percentage r , it is determined by the expression:

$$C_O = BS_N \times opex(BS_{XN}) \quad (6)$$

with $opex(BS_{XN}) = opex(BS_{X(N-1)}) \times (1 - r)$, and where $opex(BS_{XN})$ is the operation unit cost of a base station at year N brought back to technology X .

As a matter of fact, the operation decreases each year with a positive constant reducing percentage r . This decrease is due to the fact that a piece of equipment is used, some mastery is acquired which reduces the operation cost as the years go.

The access total cost of a technology X is the sum of total CAPEX, OPEX total operation over the whole duration of the project and allied expenses. The allied expenses include the investment and operation expenses of the liability infrastructures as well as those of energy workshops. Taking into account, on the one hand, that the OPEX cost represents 5% of the CAPEX costs [12] and, on the other hand, that the energy OPEX cost represents 25% of the CAPEX in energy [12], the investment and operation costs of the liability infrastructures as well as those of the energy workshops, while simultaneously integrating the OPEX and CAPEX costs, are determined by the following expressions:

$$CTI_X = 1.05 \times BS_N \times c_i \quad (7)$$

$$CTE_X = (1.25 \times c_e) \times \sum_{k=0}^T BS_{NXk} \quad (8)$$

with c_i the liability infrastructure unit cost and c_e the energy unit cost.

Thus, the allied expenses CC are given by the expression:

$$CC = CTI_X + CTE_X \quad (9)$$

whereas the access total cost is given by the following relationship:

$$CTA_X = CC + C_C + \sum_{k=0}^T C_{OXk} \quad (10)$$

Expressing the OPEX summation of the access technology and using equation (5), it is possible to write:

$$\sum_{k=0}^T C_{OXk} = BS_0 \times opex(BS_{X0}) + BS_1 \times opex(BS_{X1}) + \dots + BS_T \times opex(BS_{XT}) \quad (11)$$

where $opex(BS_{X1}) + \dots + BS_T \times opex(BS_{XT})$ and $opex(BS_{X2}) = opex(BS_{X1}) * (1 - r)$

The following expression is obtained:

$$\sum_{k=0}^T C_{0Xk} = opex(BS_{X0}) \times [BS_0 + BS_1 \times (1 - r)^1 + \dots + BS_T \times (1 - r)^T] \quad (12)$$

Thus, the total cost of the access network is determined by the following global expression:

$$CTA_X = CC + C_c + opex(BS_{X0}) \times [BS_0 + BS_1 \times (1 - r)^1 + \dots + BS_T \times (1 - r)^T] \quad (13)$$

In practice, a region or an area is the object of a commercial launching when the total set of stations are deployed. This simplifies the expression (13) which becomes:

$$CTA_X = BS_X \times \{1.05 \times c_i + (1.25 \times c_e) \times (T + 1) + capex(BS_X) + opex(BS_{X0}) \times [1 + (1 - r)^1 + \dots + (1 - r)^T]\} \quad (14)$$

$$CTA_X = BS_X \times \{1.05 \times c_i + (1.25 \times c_e) \times (T + 1) + capex(BS_X) + opex(BS_{X0}) \times [1 + (1 - r)^T] / [-r]\} \quad (15)$$

For a given technology, it is possible to establish a connection between the $opex(BS_{X0})$ and the $capex(BS_X)$. Suppose in this case that this connection is α , then expression (16) becomes:

$$CTA_X = BS_X \times \{1.05 \times c_i + (1.25 \times c_e) \times (T + 1) + capex(BS_X) [-r + \alpha + \alpha \times (1 - r)^T] / (-r)\} \quad (16)$$

Then, we can finally get BS_X expression as follows:

$$BS_X = \frac{CTA_X}{\{1.05 \times c_i + (1.25 \times c_e) \times (T + 1) + \alpha - \alpha \times \frac{[1 + (1 - r)^T]}{[-r]}\}} \quad (17)$$

In a given locality, the access technology X to choose will be the one that will have the lowest access total cost CTA_X among all the technologies submitted to this algorithm.

This profitability makes it possible to evaluate the total amount of the subsidy necessary to achieve the project but also the adequate purchasing power (ARPU) needed to ensure the population accessibility to the service. The analysis of the model shows that the whole set of the expenses from which the subsidy on the project duration is subtracted has to be lower than what the operator will earn over the same duration (number of subscribers over the project study duration multiplied by the ARPU).

III. RADIO TRANSMISSION MODELLING APPROACH

The radio transmission model presents all the equations that ensure the transmission of information between covered area and the core of the network through the national backbone. As with the access model, the elaboration of the transmission model follows several steps. These steps are presented through the following lines:

Determining the number of active relay stations to reach the backbone is estimated with the following formula:

$$N_{XT} = \frac{D}{D_{XT}} \quad (18)$$

where the number of active relay stations N_{XT} is determined by the ratio of the distance between the operator network (D) over the range of an XT (D_{XT}) radio transmission technology. Let's consider that the cost of an active relay station is the same as that of the main station. The verification of the capacity provided by XT transmission technology consists in reassuring that the throughput offered by the transmission technology can withstand the throughput that will be submitted to it during the entire study period of the project. This is done based on the following inequality:

$$BP_{XT} > (A5voice_T * \alpha) + A5data_T \quad (19)$$

The (19) inequality above means that the capacity of the transmission technology is greater than the sum of the total off-net voice rate ($A5voice_T * \alpha$) in addition to the total data rate in the previous project year of study ($A5data_T$) to ensure that the dimensioning is adapted throughout the duration of study T of the project. The total CAPEX cost of the XT transmission technology is given by the following formula:

$$B2_{XT} = CAPEX_{XT} * (N_{XT} + 1) \quad (20)$$

The total CAPEX cost of transmission technology ($B2_{XT}$) is calculated by multiplying the number of active relay stations plus the main station by the CAPEX of a transmission technology station. The total cost of the OPEX of the XT transmission technology is given by the following relation:

$$B3_{XT} = B3_{XT0} * \left[\frac{1 - (1 - r)^{T+1}}{r} \right] \quad (21)$$

As for access technology, the OPEX transmission technology is clean every year. Indeed, the latter is subject to a decrease over the years due to the reduction coefficient "r" of the OPEX in transmission. One gets:

$$B3_{XTN} = OPEX_{XTN} * (N_{XT} + 1) \quad (22)$$

which represents the cost of the OPEX of a transmission technology XT to year N ; the number of transmission stations is multiplied by the cost of OPEXs in year N . However, OPEXs are reduced each year due to the progressive control of the technology. The cost of the OPEX $B3_{XTN}$ is therefore a geometric sequence based on $(1 - r)$ with $r \neq 1$ and $r \neq 0$. Thus, one can easily determine the sum of the OPEX of the radio transmission technology XT over the duration of the project as follows:

$$\sum_{k=0}^T B3_{XTk} = B3_{XT0} * \left[\frac{1 - (1 - r)^{T+1}}{r} \right] \quad (23)$$

This justifies the expression of the total cost of the OPEX $B3_{XT}$ over the study duration T of the project.

In order for the operator to have access to the Internet, he must pay an annual cost according to the total data throughput of a specific year. To actually calculate this cost over the duration of study T of the project, the following expression (24) can be used:

$$B3data = B6data * \sum_{k=0}^{T-1} A5data_k \quad (24)$$

where the total cost of Internet access ($B3data$) is calculated by multiplying the total data rate over the entire duration of the project ($\sum_{k=0}^{T-1} A5data_k$) by the cost per Mbps which is set by the legislation of a given country ($B6data$).

To allow network users to communicate with subscribers of another operator, the operator must pay a cost of voice-over-net traffic. The total cost of voice over-net traffic can be written as :

$$B3voice = (\sum_{k=0}^{T-1} A5voice_k) * \alpha * B6voice \quad (25)$$

The total cost of off-net voice traffic is determined by first calculating off-net voice traffic which is a portion of overall voice traffic. Then one multiplies the overall voice traffic over the entire duration of the project ($\sum_{k=0}^{T-1} A5voice_k$) by the percentage of voice-over-net traffic (α). The off-net voice traffic thus obtained is multiplied by the cost per Mbps ($B6voice$) which is set by the legislation of a given country.

The total associated transmission cost representing the passive infrastructure costs (Mat, Shelter, Pylon) as in the access model, is given by:

$$CTI_{PXT} = (N_{XT} + 1) * CUI_P * [1 + 0.05T] \quad (26)$$

The method applied to determine this associated costs in transmission is similar to that described in access. Actually, the total cost in passive infrastructure of transmission technology (CTI_{PXT}) is calculated by multiplying the number of transmission stations ($N_{XT} + 1$) by the infrastructure cost of a transmission station (CUI_P) and by $[1 + 0.05 * T]$ to be able to directly cover the cost of OPEX and CAPEX in passive infrastructure simultaneously as OPEX in infrastructure represents 5% of CAPEX in passive infrastructure (CUI_P) and the number of transmission equipment remains the same over time T study project.

IV. CASE STUDY

In order to apply and assess the proposed approach, as an illustration, the Ouaddaï (Chad) region is considered. It has an area of 36,685 km² including a population of 1 367 166 inhabitants. This area includes three localities with identical needs in data rate/inhabitant but the needs in bandwidth differ from a locality to another. Tables 1 and 2 below sum up the set of collected data.

Table 1 represents the actual data of the Ouaddaï region (Chad) with locality1 situated in city centre, locality 2 situated in periphery and locality3 situated in rural zone. This distribution corresponds to the administrative division: the zone corresponds to the region; the locality corresponds to the three departments which are distributed into communities.

TABLE I
OUADDAÏ AREA BASIC DATA (SOURCE ARCEP CHAD)

Data	Locality 1	Locality 2	Locality 3
Area (km ²)	11 611	15 229	9 845
Population	852 389	388 448	126 329
Penetration rate	43.66	43.85	44.40
Need in output/subscriber (Kbps)	256	256	256
Population Ps	371 547	170 755	56 078
Addressed Population (PA)	209 647	95 350	31 121
Appropriate bandwidth (Bp_A) by Mbt/s	53 669 660.67	24 409 480.70	79 67 025.41

This table makes out for each considered locality:

- the population data (geographical area, number of inhabitants);
- the subscribers park of the set of electronic communications services;
- ICT penetration rate;
- needs in output/subscriber and necessary bandwidth (Bp_A).

The analysis of table 1 reveals that according to IUT's definition of universal access, it is important to have an output of 256Kbps to supply the necessary services. For the set of considered localities, a penetration rate inferior to 45% is recorded. The penetration of services related to the data is low, which justifies the significant need in bandwidth of the localities.

Table 2 below gives the outputs supplied by the different technologies, the surfaces covered by a base station (BS) of technology X as well as the maximum capacity of BS's. It also shows the CAPEX, OPEX of the base stations by technology and the cost of liability infrastructures as well as those energy-related.

TABLE II
DATA RELATED TO TECHNOLOGIES

Data	WIFI	WIMAX	CDMA
Data rate (D_X)	54	70	3.1
Surface covered by BS (S_{BSC})	0.13	200.96	5024
BS capacity ($CapBS_X$)	100	30	64
CAPEX (BS_X) in Euro	13.71	1 494	68 597.561
OPEX (BS_X) in Euro	2.06	224.08	10 289.63
CTA (Euro)	1 524 390.24	1 524 390.24	1 524 390.24
Ci	1	2 003	10 015
Ce	7 621.95	25 914,63	85 129.57

After analysing tables 1 and 2, the number of base stations by technology is determined following equation (17) and according to the following conditions:

- variation of duration T of the project as well as that of the OPEX coefficient reduction τ ;
- only at the variation of the reducing coefficient τ ;
- variation of coefficient m linked to the coverage in accordance with equation (4).

Figure 1 below represents the number of stations by technology according to the variation of the reducing coefficient and the project duration. This graph makes it possible to see the evolution of the BS_X of the zone, for the

same τ and T the number of BS_X differs according to technology X. It is worth noting that if the project duration T increases, the number of BS_X decreases.

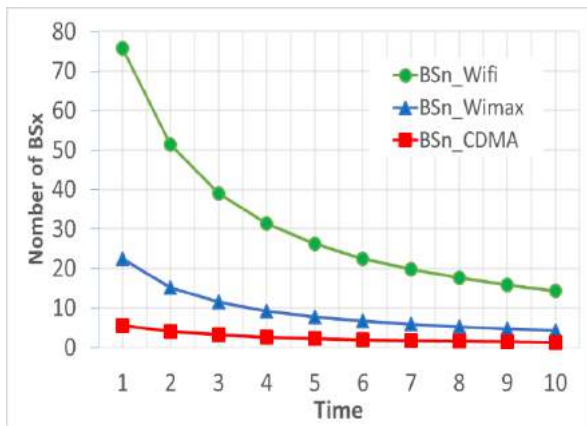


Fig. 1. Evolution of the number of base stations by technology according to a variation of duration T and reducing coefficient.

Figure 2 shows the evolution of the base stations of three access technologies (Wi-Fi, WiMAX and CDMA) in accordance with the variation of reducing coefficient r . Based on the depreciation of the telecommunications equipment, the project duration T is 5 years. It is established that if the duration T is constant, the variation of the reducing coefficient r has no effect on the number of BS_X . The BS_X by technology practically remains constant even if r varies.

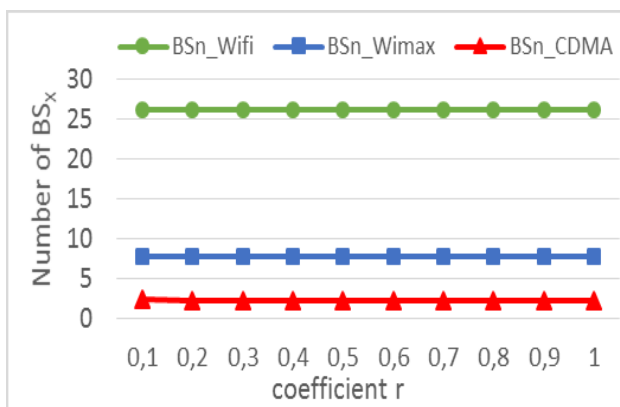


Fig. 2. Evolution of the number of base stations by technology in accordance with coefficient r .

Figure 3 shows the evolution of the number of base stations of three technologies following the deployment approach directed to coverage and capacity coverage objectives. When m varies, it is noted that for a technology X , the needed number of stations varies significantly. It is worth indicating that for the two extreme values (0 and 1) of m , the base station number decreases very significantly following technology X . This shows that it is easier to reach the coverage goals than those related to the quality of service and capacity. Thus, it is noted that the CDMA technology allows the coverage objectives to be reached more easily, the Wi-Fi and WiMAX, on the other hand, are more efficient for capacity oriented deployment.

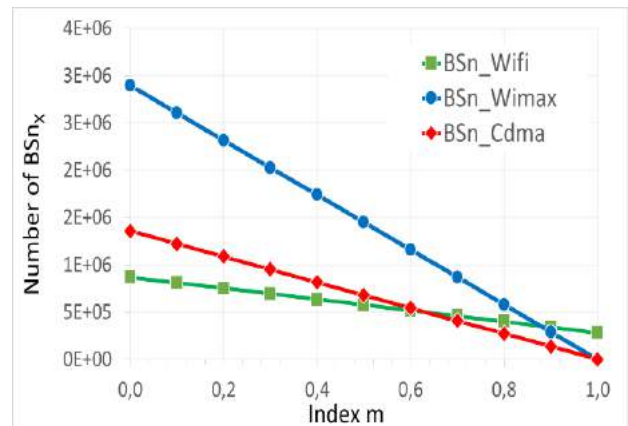


Fig. 3. Evolution of the number of base stations by technology according to the m variation.

TABLE III
OURA AREA BASIC DATA (SOURCE ARCEP CHAD)

Data	Access	Data	Transmission
Area (Km ²)	15 229,0	Space segment rental cost for 1 Mbps	7000 euros/month
Rate of growth	3,1	Local backbone rental cost	147000/Mbps
Need in output/subscriber (Kbps)	256	Percentage of off-net voice traffic (%)	5,6
Need for speech rate (in kbps)	9,1		
Population with access to the service (voice and data)	170 756	Distance between access zone and backbone (km)	142
Growth rate subscribers to the service	12,1		
Contention rate	1:97	-	-

To illustrate the combined case of access and transmission, we present in the last part of this section the results of a real case of universal access project. The target area is OURA, a rural region of Chad which information for the deployment of technologies for universal access is presented in Table 3.

The project is studied over a 5-year T -term. Given that it is a rural area, the option considered includes a solar power equipment as cost effective solution. Passive infrastructures as Shelter and pylons allow the technologies to reach their maximum range.

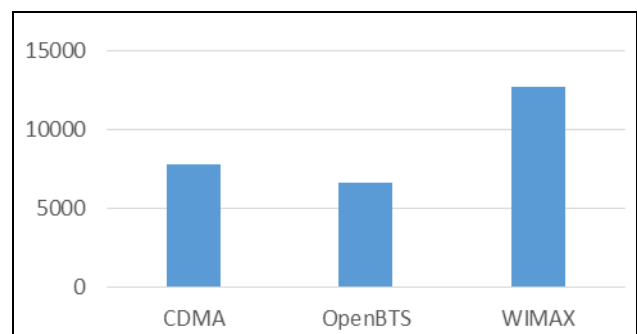


Fig. 4. Universal service fund grant cost comparison in CFA for a different access technologies using microwave for transmission.

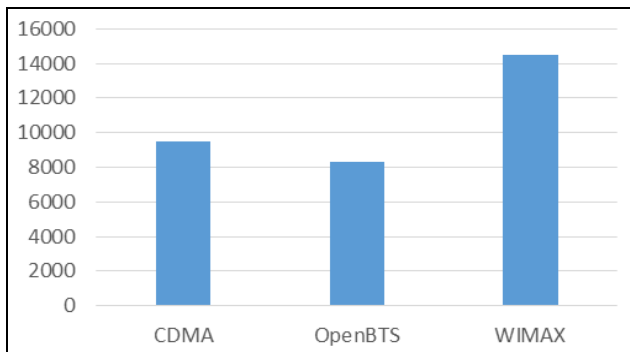


Fig. 5. Universal service fund grant cost in CFA comparison for a different access technologies using Wimax for transmission.

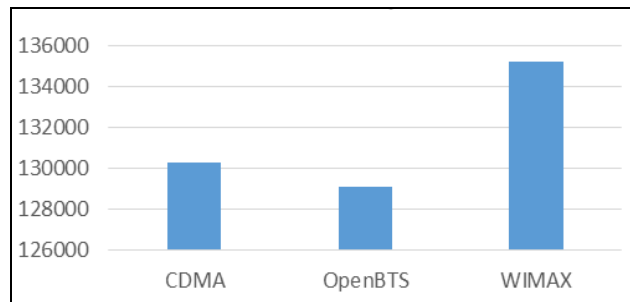


Fig. 6. Universal service fund grant cost in CFA comparison for a different access technologies using VSAT system for transmission.

As the penetration rate of service is about 44% with these figures, we have planned for this test a projected service penetration rate of 50%. Several combinations of access and transmission technologies have been investigated as shown in Fig.5, 6 and 7. The amount of 655.55 FCFA correspond to one Euro.

The analysis of these figures shows that the Open BTS-microwave combination is the most suitable at Oura region for this universal access project. The amount of the subsidy is 10 053 424 Euros. The people of this zone will have to pay to the operator about 9.12 Euros per year or at least 0.76 Euro per month to obtain the services. The operator will make a turnover of 1057810 Euros out of the five (5) years of study of the project.

It should be noted that for the purposes of these tests, it is assumed that the WIMAX and VSAT technologies can transmit the calculated bandwidths. To enable such transmission capacity, new transmission techniques such as MIMO for WIMAX and large VSAT stations should be used, given the density of the population, which will lead to even higher costs. For VSATs, the case is even more critical because the rental cost of the space segment is immeasurable. This confirms that VSATs cannot be used for areas with a relatively high population for universal access projects at affordable cost.

V. CONCLUSION

The aim of this paper was to suggest an optimal model to define the network architecture based on radio technologies for universal access and services. This approach makes it possible on the basis of the universal service access fund allocated to each locality to determine the communication needs in terms of output, bandwidth and the amount of equipment needed by technology. To ensure ideal overall accessibility in an area i , the technical solution envisaged must integrate the specific economic and geographical

constraints of that locality. Also, the simulations showed that several possibilities could be envisaged to remedy the constraints linked to the development of universal access. However, the choice of the appropriate solution depends on the cost C of the technologies to be deployed in an area i calculated on the basis of its inputs

The results of the simulations of the UAI, orient us towards combined solutions (access and transmission) thanks to the application to the Ouaddaï and Oura areas located in Chad which allow the gradual deployment policy, distributed over a duration, of the cheapest cost coefficient network.

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Bachar Saleh Idriss was born in CHAD on 27/09/1984. He got the Ph.D. degree in telecommunication from the University of Limoges, France, in 2016. He is the GENERAL DIRECTOR of National School of Information and Communication Technology from June 05 up to now. From August 31, 2010 to June 05 GENERAL DIRECTOR of the Regulatory Authority for Electronic Communications and Posts (ARCEP CHAD). From 2010 to May 31,

2011, he was president of the Association of Telecommunications Regulators of Central Africa (ARTAC) and Vice President of the Commission recast texts Officer (Electronic communications, telecommunications regulation and Postal, cybersecurity, Cyber criminality). His research activities cover low cost access network and universal services solution appropriate to Africa.

Dr. BACHAR is member of the “Association pour le Developpement de l’Informatique Libre (ADIL)” and the REPTIL in CHAD.



Ahmed D. KORA was born in Parakou (Benin Republic) on May 17, 1971 He is graduated in Physics Sciences in 1998 from “Faculté des Sciences Techniques” at “Université d’Abomey-Calavi”, Bénin, where he got his Diplôme d’Etude Approfondie (DEA) in Material Sciences in 2000. In 2003, he received a Master “Réseaux Télécoms” degree from “Ecole Supérieure Multinationale de Telecommunications” (ESMT) and the Ph.D. degree in telecommunication from the University of Limoges, France, in 2007.

He is currently with the ESMT and Head of Research and Innovation Department. His research area covers communications, radio and optical networks system architecture, universal access, mobile network quality of service and quality of experience, low cost IT systems for development, etc. Prof. KORA is IEEE member and also member of Fiber Optic Association.



Roger Marcelin FAYE was born in Thiès (Senegal) on 09/12/1961. He received the engineer degree in Electrical Engineering from ENSUT (Ecole Nationale Supérieure Universitaire de Technologie) Dakar-Senegal in 1989. He obtained the MSc in Control and Modelling Industrial Processes from Paris 12 Val de Marne University, Paris-France in 1994 and his PhD in Automatic Control and Operational Research from University of Toulouse III

Paul Sabatier, Toulouse-France in 1999.

He is currently full Professor at Ecole Supérieure Polytechnique (ESP) and was the head of Electrical Engineering department at ESP from 2010 to 2012. He is author and/or co-author of several publications and two books in the fields of Automatic Control. His research activities cover but not limited to modelling systems and to IT solutions for Africa.

Prof. FAYE is member of the Senegalese society of complex systems.



Christelle Aupetit-Berthelemot was born in Limoges (France) in 1971. She received the engineer degree in telecommunication from ENSIL (Ecole Nationale Supérieure d’Ingénieurs de Limoges ENSIL-France) in 1995. The same year, she received the M.S. degree and in 1998, a PhD degree in High Frequency and Optic Telecommunications from University of Limoges. She is currently full Professor and the head of Electronic and Telecommunications

department at ENSIL. Her current research activities concern optical telecommunications and microwave photonics. Particularly, her interests are focused on the study of the impact of the components on the system performances, integration of digital techniques of signal processing in optical communication, Radio Over Fiber, and optoelectronic devices characterization. She has been involved in several Cooperative Projects. She is author and/or co-author of more than 100 publications. Prof. AUPETIT-BERTHELEMOT is editor in Chief of J3EA review and member of Optical French Society (SFO), of french club EEA and GDR SoC²